Application of vessel-based LiDAR to quantify coastal retreat in Monterey Bay, CA.

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Abstract

Coastal erosion has become a prominent issue in Monterey Bay, California. Areas at high risk include native coastal dunes, private and public beachfront properties, municipal sewage lines, and areas of the highway 1 corridor. Traditional airborne LiDAR has been an effective but costly method for measuring coastal topography by providing high resolution and broad coverage. In 1997 and 1998, NASA, USGS, and NOAA collaborated to conduct pre-and post-El Niño airborne LiDAR surveys of the California coastline. Since then, there have been no further, publically available LiDAR surveys of the Monterey Bay shoreline. The goal of this project is to apply a vessel-based LiDAR system to measure coastal geomorphology, determine the efficacy of vessel-based topographic LiDAR for mapping coastal geomorphology, and quantify the spatial distribution of coastal retreat for Southern Monterey Bay, California. The area of study was the Monterey Bay coastline from Monterey harbor, CA north to Marina State Beach at Reservation Road. Sea cliff morphology data were measured on Dec 9thand 10th, 2008 through the use of a terrestrial LiDAR system mounted atop the CSUMB Seafloor Mapping Lab's R/V VenTresca. These vessel based LiDAR data were compared with 1998 NOAA Airborne Topographic Mapper LiDAR data using mapping and spatial analysis tools in ArcGIS to quantify the spatial distribution of coastal retreat and calculate annualized rates of erosion for the Monterey Bay shoreline over the past decade. In keeping with previous published work based on other methods, preliminary results show positive relationships between both dune apron retreat and volumetric change along an increasing gradient from south to north. Average dune apron retreat rate for the study area was 0.92 m/yr. We conclude that vessel-based mobile topographic LiDAR is an efficient, cost-effective, high resolution method for annual sea cliff geomorphic change detection highly useful for coastal planning.

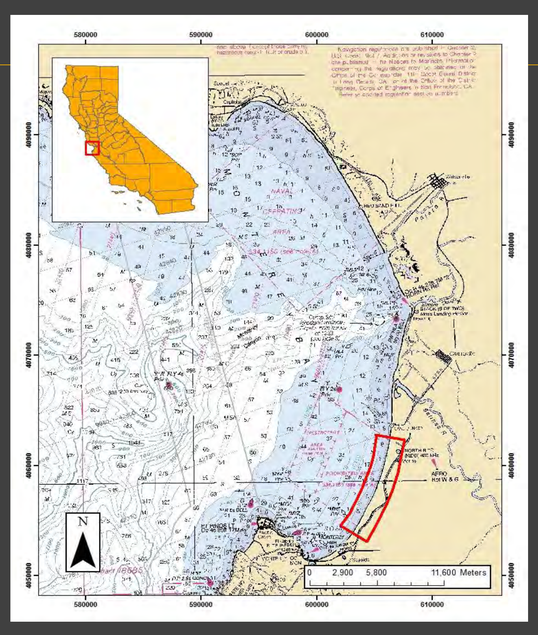


Figure 1 (right): Figure 1: Study Area – Red polygon enclosing the Monterey Bay coastline from Sand City , CA to Marina State Beach at Reservation Rd. Background: NOAA nautical chart 18680. Coordinate System: UTM Zone 10

Methods

Advances in LiDAR technology have led to new methods with increasingly precise measurements and accurate quantification of topographic data. In this study, vessel based mobile marine terrestrial LiDAR was used to collect sea cliff morphology data at sub meter resolution in Monterey, CA. Mobile marine LiDAR is a terrestrial laser scanner mounted on a moving platform. This method produces high-resolution terrain data, provides mobility and is relatively cost efficient compared to traditional airborne LiDAR surveys.

Photo above: Jere Brantner, Katie Glitz, and Steven Quan next to the Riegl side-looking LIDAR sensor mounted atop SFML's *R/V VenTresca*.

Riegl LMS-Z420i
Photo from www.riegl.com

The Riegl LMS-Z420i is the terrestrial laser scanner operated by the CSUMB Seafloor Mapping Lab (SFML) and was mounted atop the SFML R/V VenTresca. The Applanix Position and Orientation System for marine vessels (POS/MV) was used in conjunction with the LMS-Z420i to georeference and correct each LiDAR data point for vessel attitude and tidal variation.

Applanix POS/MV
Photo from www.applanix.com

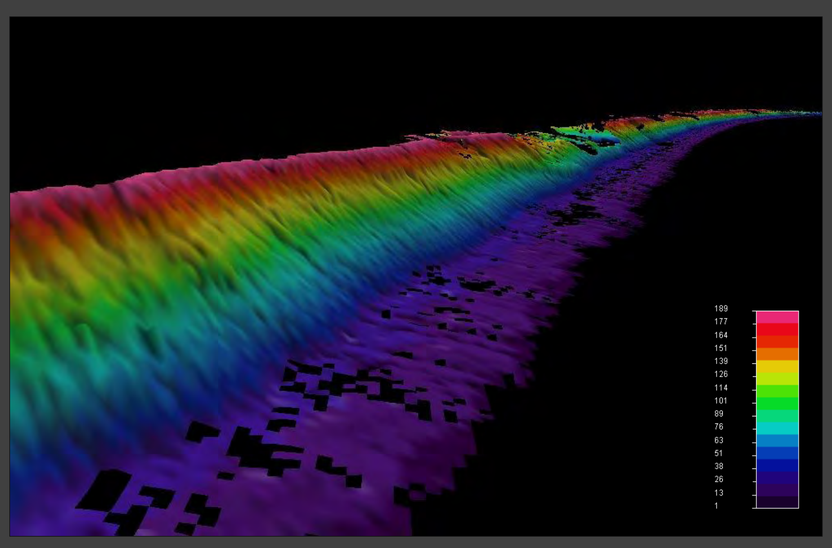


Figure 2 (right): Digital seacliff surface representation of 2008 vessel-based LiDAR data in Fledermaus 6.7. Color ramp represents elevation in meters. Location: Coastline of Southern Monterey Bay.

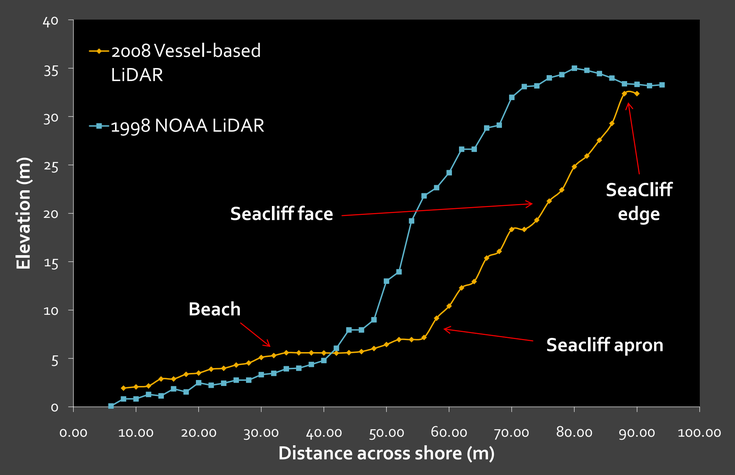


Figure 3 (above): Shore-normal profiles of LiDAR derived data for 1998 and 2008 of the seacliffs at Fort Ord dunes state park. The blue line represents the beach / seacliff profile in 1998 and the orange line represents the beach / seacliff profile in 2008.

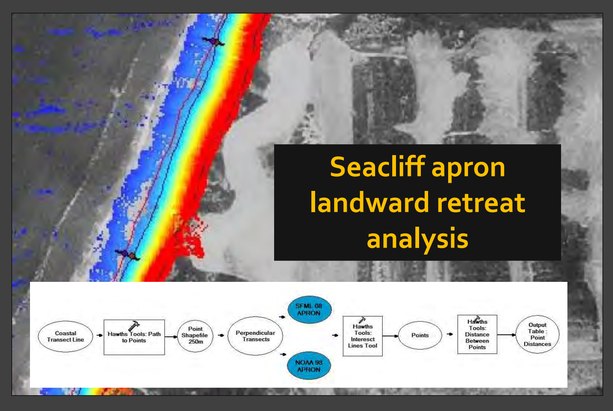


Figure 5 (above): Points were generated every 250m along slope derived contour lines delineating seacliff apron from 1998 NOAA LiDAR data(red polyline) and 2008 SFML LiDAR data (blue polyline). Transects were generated between respective points on 1998 and 2008 dune apron lines to calculate horizontal distances between points relative to their transects.

Preliminary Results

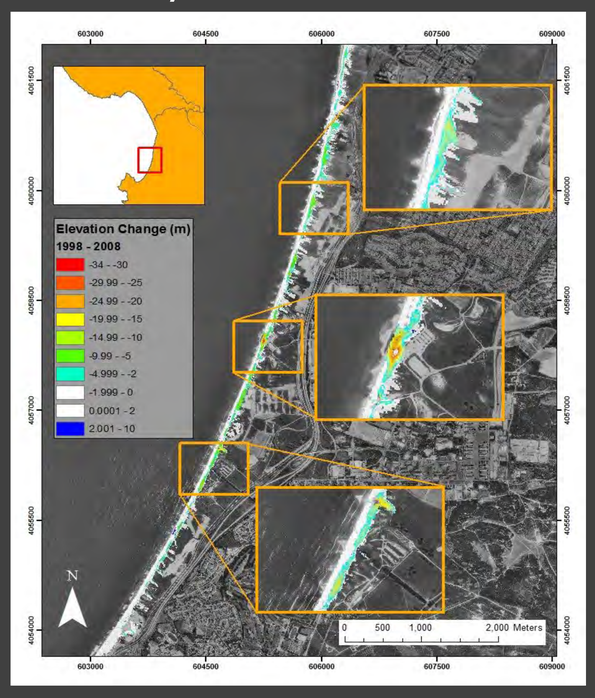
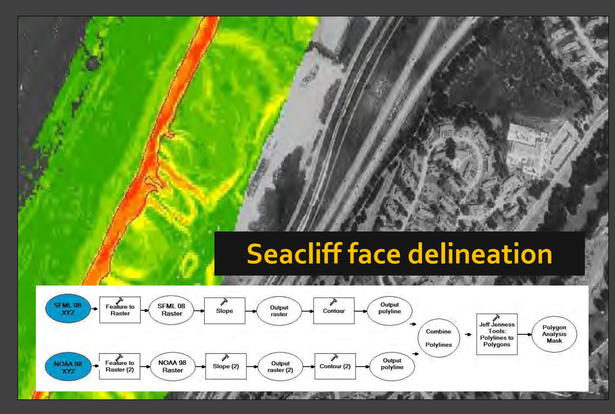


Figure 8 (above): Raster subtraction in ArcGIS between 1998 NOAA LiDAR data and 2008 vessel-based LiDAR data showing elevation change. Green, yellow, orange, and red depict a loss of sediment. Blue depicts sediment deposition. Background: USGS DOQ.

Figure 4 (below): Seacliff faces were delineated using Spatial Analyst and Jeff Jenness Tools on slope rasters derived from LiDAR data. Oranges depict steep slopes and greens represent flat slopes. Slope derived contour lines were created at the break in slope between the seacliff apron and the beach, and between the seacliff edge and the seacliff face. Red polylines delineating seacliff apron and seacliff edge create an analysis mask to focus the area of interest to just seacliff faces and minimize noise from ephemeral beach elevation change.



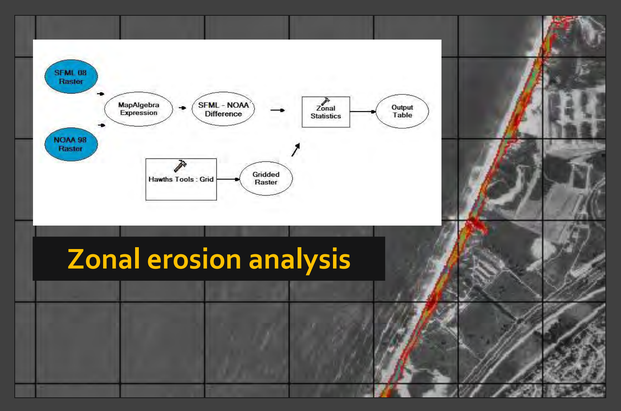
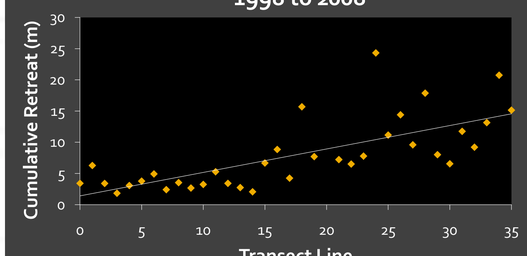


Figure 6 (left): The Southern Monterey Bay coastline was gridded to 500m x 500m cells using Hawth's Tools (Beyer 2004). Spatial Analyst's Zonal statistics tool was used to quantify volumetric change for each 500m latitudinal row (longitudinal change).

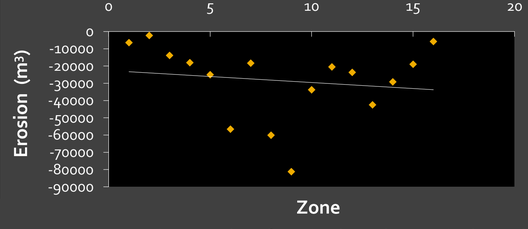
Landward seacliff apron retreat from 1998 to 2008



Residuals:				
Min	1Q	Median	3Q	Max
-6.134	-2.198	-0.704	1.253	13.890
Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.404	1.315	1.068	0.293
Transect	0.376	0.065	5.825	1.62E-06

Figure 6 (top): Scatter plot of seacliff apron retreat from 1998 to 2008 for each transect vs. transect number and output table from linear regression analysis of cumulative dune apron retreat for each transect vs. transect number. Transects were numbered starting from 1 at Sand City and ending at 16 at Marina State Beach.

Sand volume lost to the littoral zone from 1998 to 2008



Residuals:				
Min	1Q	Median	3Q	Max
-52360	-5863	7310	11644	27957
Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-22588.9	11671	-1.935	0.0734
Transect	-696.2	1207	-0.577	0.5732

Figure 7 (top): Scatter plot of sand volume lost to the littoral zone in m³ for each 500m latitudinal zone vs. zone number and output table from linear regression analysis of erosion in m³ for each 500m latitudinal zone and zone number. Zones were numbered starting from 1 at Sand City and ending at 16 at Marina State Beach.

Discussion

Zonal erosion analysis shows a slight increase in sand volume lost to the littoral zone vs. longitude, but with no significant relationship(p>0.05). A significant relationship (p<0.05) was found between seacliff apron landward retreat rates and transect number for this study area. Evident spatial trends from the zonal erosion and seacliff apron landward retreat analysis are reasonable as wave energy and overall wave exposure is greater towards the center of Monterey Bay. Figure 9 shows the distribution of wave energy for the Monterey Bay region during a 2009 strong winter storm. The spatial distribution of wave energy appears to be correlated with the spatial patterns of landward seacliff apron retreat indicating wave energy could be a significant environmental factor in landward seacliff retreat, a topic for future research.

The calculated average seacliff apron retreat rate of .92 m/y is in agreement with previous studies by Thornton (et al 2006), which measured erosion rates that vary from about 0.5 m/yr at the south end of Monterey Bay to 1.5 m/yr mid-bay during the 1980s to 1993. This indicates erosion rates have remained relatively constant over the last 20 years.

Results from both zonal erosion analysis and seacliff apron landward retreat analysis may be on the conservative side as the 1998-2008 time scale was not large enough to capture the impacts of a strong El Niño, which may change results dramatically. Thornton et.al.(2006) calculated the volume loss of the dune in southern Monterey Bay during the 1997–1998 El Niño winter at 1,820,000 m³, which is nearly seven times the historical annual dune erosion.

Potential sources of error associated with this methodology could include misregistration of LIDAR datasets and misrepresentation of seacliff apron/seacliff edge locations due to the variability of change in magnitude of slope at the break in slope areas . These potential factors will be accounted for in future analyses.

The implementation of vessel based LiDAR proved to be an effective and cost efficient method to frequently measure sea cliff geomorphology at very high resolution. The amount of detail vessel based LiDAR provides is critical for accurate and precise quantification, analysis, and modeling of geomorphic coastal processes. Although the low, horizontal view point of vessel-based LiDAR can miss flat spots above the level of the sensor and topographic lows behind berms and dunes, thereby precluding the ability to measure second order dunes, this view point is optimal for measuring lateral erosion and deposition of sea cliff faces

Further research will include an analysis of the entire Monterey Bay coastline from Monterey to Santa Cruz, the environmental factors that contribute to the coastal erosion processes at play, and the impacts of this year's 09-10 El Nino winter storms.

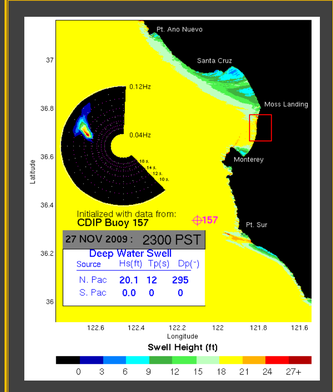


Figure 9 (above). The Coastal Data Information Program Nowcast model of swell height for the Monterey Region during a strong storm in November 2009. cdip.ucsd.edu. Red polygon shows the approximate study region.

References

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Thornton EB, Sallenger A, Sesto JC, Egley L, McGee T, Parsons R. 2006. Sand mining impacts on long-term dune erosion in southern Monterey Bay. Marine Geology 229: 45- 58.